Parametric Approaches for Refractivity-from-Clutter Inversion

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LONG-TERM GOALS

The long term goal of this project is to develop inversion approaches that enable the estimation of refractivity profiles and the associated uncertainty. Furthermore, we will develop methods for mapping the refractivity parameters and their associated uncertainty into propagation.

OBJECTIVES

The objective of this proposal is the development of parametric approaches for the inversion of radar clutter data to estimate atmospheric refractivity over land and sea. Refractivity inversion algorithms using land clutter with and without radar phase will be developed. Over the sea we will further develop our approaches to carry out estimation in time and space of the refractivity.

APPROACH

We have considerable experience in carrying out refractivity estimation from ocean clutter data [Gerstoft et al., 2003a, 2003b, Gerstoft et al., 2004; Rogers et al., 2004]. Little has been done to indicate the quality of the solution for each parameter, either with the variance of the parameter estimate or preferably the complete *a posteriori* distribution. We have already done much work on this in an ocean acoustic context, but this has not been explored in our refractivity from clutter (RFC) processing to date. This will entail developing likelihood formulations and importance sampling algorithms. This inversion approach will show the information content in the data, the importance of each parameter, and the quality of the inversions. Another related topic is that in RFC inversions, we commonly invert each data block independently. When these inversions are close in time (i.e., successive looks in time at the same azimuth) or space (i.e. adjacent azimuths), it should be beneficial to use the results of the previous inversion as a starting condition for the next inversion. A natural framework for this is a Bayesian approach where the posterior of the last inversion becomes the prior for the current inversion. For this investigation, the Bayesian approach will be implemented using a Metropolis-Hastings Gibbs sampler.

WORK COMPLETED

A method for estimation of the radio refractivity from radar clutter using Markov Chain Monte Carlo (MCMC) samplers with a likelihood-based Bayesian inversion formulation has been introduced. This approach enables us to obtain full *n*-dimensional posterior probability distributions for the unknown parameters as well as the maximum likelihood solution itself [Yardim 05a, 05b, 05c].

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14. ABSTRACT
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15. SUBJECT TERMS

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are needed to see this picture.

Figure 1 Clutter map from Space Range Radar (SPANDAR) at Wallops Island, VA.

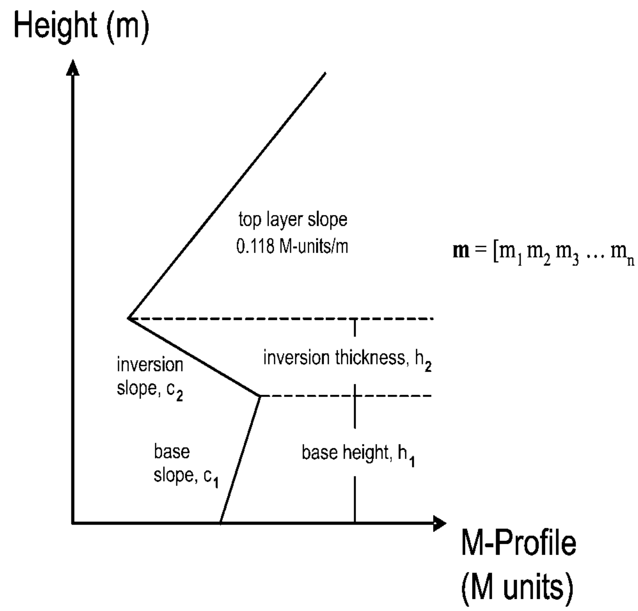

Figure 3 The 4-parameter tri-linear M-profile model used in this work.

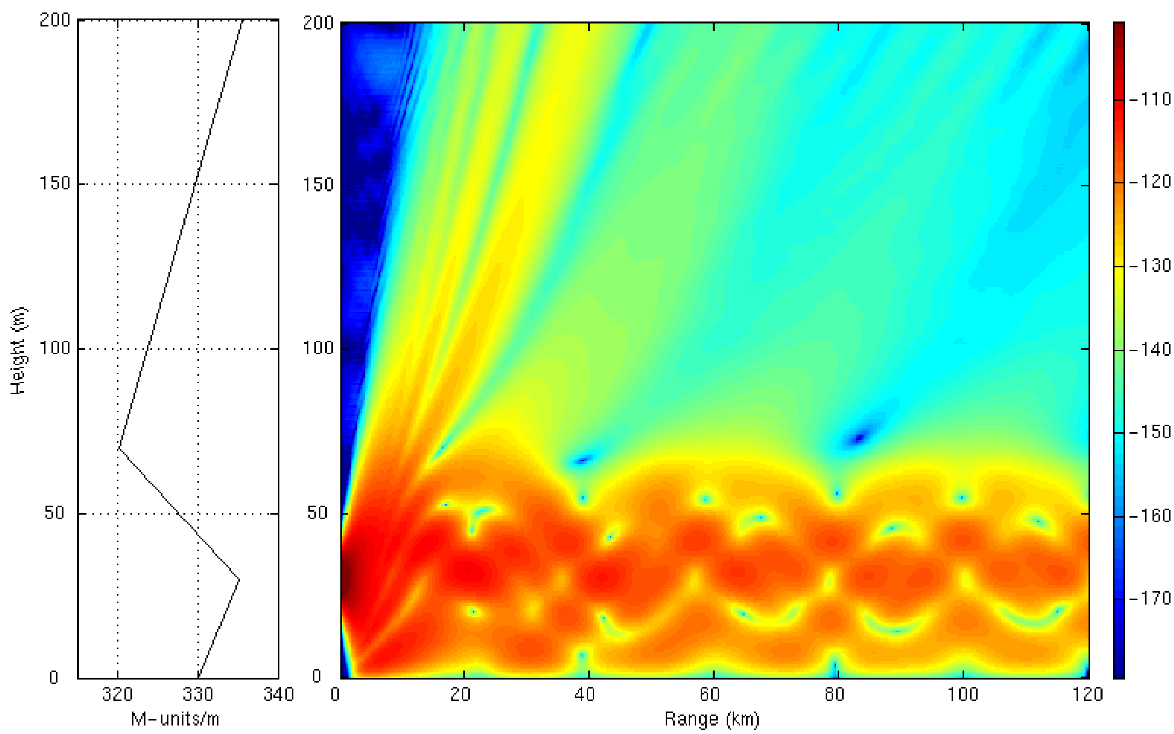

Figure 2 Tri--linear M-profile and its corresponding coverage diagram.

RESULTS

An accurate knowledge of radio refractivity is essential in many radar and propagation applications. Especially at low altitudes, radio refractivity can vary considerably with both height and range, heavily affecting the propagation characteristics. One important example is the formation of an electromagnetic duct. A signal sent from a surface or low altitude source, such as a ship or low-flying object, can be totally trapped in the duct. This will result in multiple reflections from the surface and they will appear as clutter rings in the radar PPI screen (Fig. 1). In such cases, a standard atmospheric assumption with a slope of modified refractivity of 0.118 M-units/m may not give reliable predictions for a radar system operating in such an environment.

Ducting is a phenomenon that is encountered mostly in sea-borne applications due to the abrupt changes in the vertical temperature and humidity profiles just above large water masses, which may result in an sharp decrease in the modified refractivity (M-profile) with increasing altitude. This will, in turn, cause the electromagnetic signal to bend downward, effectively trapping the signal within the duct. It is frequently encountered in many regions of the world such as the Persian Gulf, the Mediterranean and California. In many cases, a simple tri-linear M-profile is used to describe this variation. The coverage diagram of a trapped signal in such an environment is given in Fig. 2.

As detailed in the paper [Yardim at 2005] we have developed a likelihood based Markov Chain Monte Carlo (MCMC) sampler, which we will compare to a classical genetic algorithm and an exhaustive grid sampling. The exhaustive grid sampling is only possible for search spaces of small dimensions.

To validate the MCMC algorithms, a comparison with the true distribution is necessary. The true distribution can be obtained by using exhaustive search, however, it is extremely inefficient and demands huge amounts of forward model runs. Even if only 25 discrete possible values are assumed for each of the 4 parameters used for the model in Fig. 2, the state space consists of 25^4 = 3.9 x 10^5 (390k) possible states. A simple range-independent tri-linear model with only 4 parameters is used since an exhaustive search would need around 10000k forward model runs for 5 parameters. Number of forward model runs needed for MCMC is proportional to the dimension so as the dimension increases it requires much fewer samples than the exhaustive search. The selected parameters are the slope and height of the base layer (c_1 & h_1) and the slope and thickness of the inversion layer (c_2 & h_2) as shown in Fig. 3. A standard atmosphere with a vertical refractivity gradient (top layer slope) of 0.118 M-units/m is assumed above the inversion layer. Parameters are selected in terms of the heights and slopes instead of the classical heights and widths (such as the frequently used inversion thickness and M-deficit) due to their relatively smaller inter-parameter correlation.

The synthetic data is generated by TPEM at a frequency of 2.84 GHz, antenna 3dB Beamwidth of 0.4 deg, source height of 30.78 m and a radar clutter standard deviation of 10 dB, a typical value reported also in Anderson [1995]. Inversion is done using four different methods for a range of 10-60 km.

The marginal distributions of the four parameters are given in Fig.4. Except for exhaustive search, the results for all others are calculated using the MC integration. Exhaustive search result (Fig. 4(a)) is obtained with 25 discrete values per parameter and390k samples whereas both Metropolis (Fig. 4(b)) and Gibbs (Fig. 4(c)) samplers use approximately 70k samples and the genetic algorithm (Fig. 4(d)) uses less than 10k samples.

All four algorithms have almost identical ML estimates for the parameters. However, it should be noted that MCMC samplers converged after collecting nearly 7 times more samples than GA. On the other hand, the distributions obtained from the MCMC samplers are closer to the true distributions given by exhaustive search.

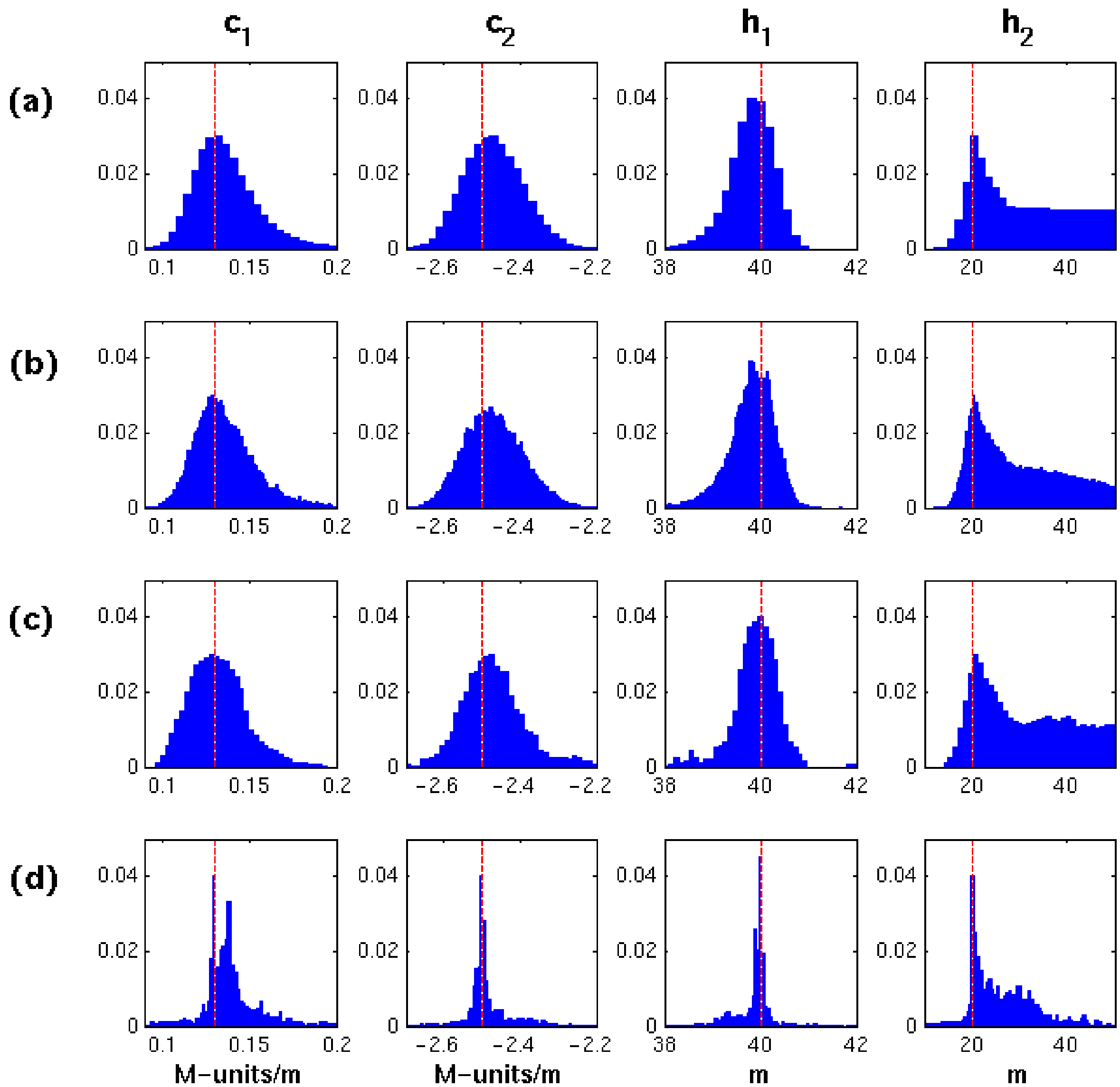

Figure 4 Marginal posterior probability distributions for the synthetic test case. Vertical lines show the true values of the parameters. (a) exhaustive search, (b) Metropolis algorithm, (c) Gibbs algorithm, and (d) genetic algorithm.

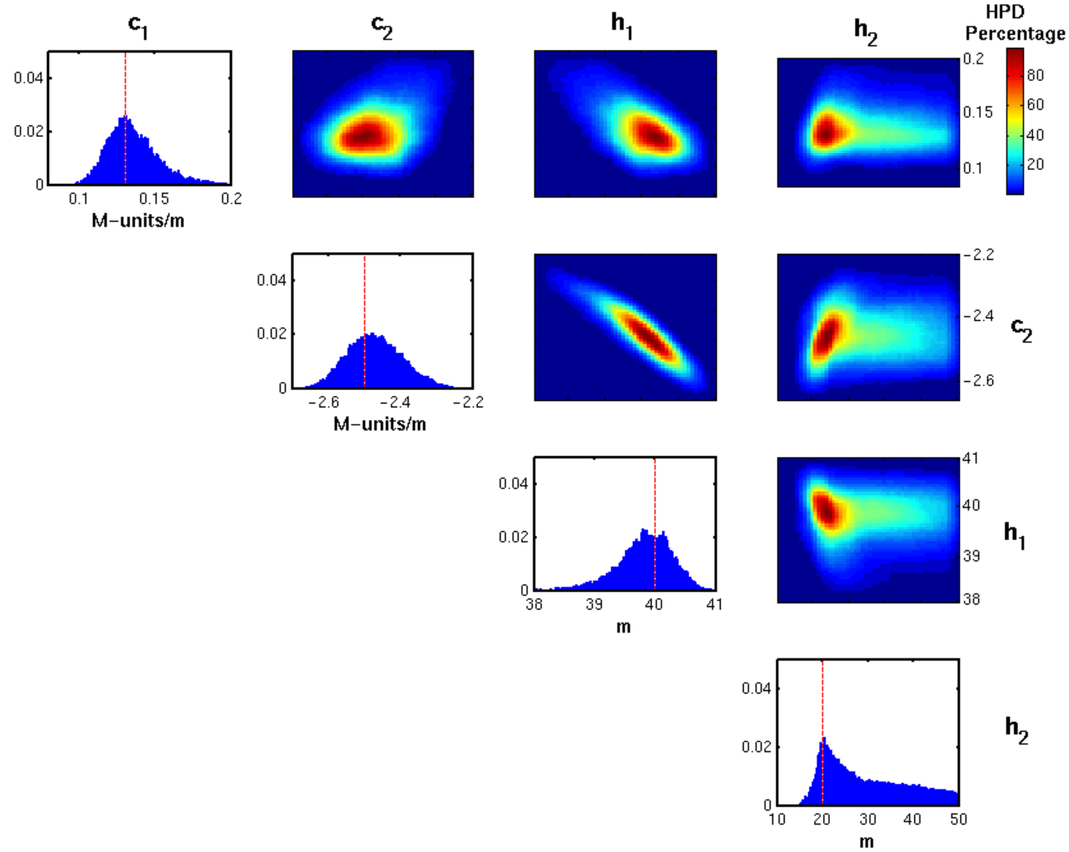

Figure 5 Both 1-D marginal (diagonal) and 2-D marginal (upper diagonal) PPDs for the synthetic test case obtained by the Metropolis algorithm. Vertical lines (in 1-D plots) and crosses (in 2-D plots) show the true values of the parameters.

Marginal and 2-D posterior distributions obtained by the Metropolis sampler are given in Fig. 5. The diagonal plots are the 1-D marginal PPDs and the off-diagonal plots are the 2-D marginal PPDs, where the 50, 75, and 95 % highest posterior density regions (HPD) are plotted, with the ML solution points (white crosses). In Bayesian statistics, credibility intervals and HPD regions are used to analyze the posterior distributions. They are very similar to the confidence interval and their definitions can be found in [Box and Tiao 1992].

Comparisons with exhaustive search and genetic algorithm results show that MCMC samplers require more samples than a classical global optimizer but are better in estimating probability distributions. The need for a relatively large number of forward model runs limits its usage as a near-real time M-profile estimator. However, it can be used together with a fast global optimizer, which will do the near-real time inversion. The MCMC sampler will then provide the credibility intervals and the uncertainties, which may not be needed frequently.

One immediate benefit of the method is the ability to assess the quality of the inversion and obtain highest posterior density (HPD) plots for other parameters that could be of interest to an end-user, such as the one-way propagation loss, propagation factor for different heights and ranges, or variability in the coverage diagrams. They can easily be obtained by post-processing the Metropolis samples of the refractivity parameters.

IMPACT/APPLICATIONS

Knowledge of refractivity profiles is important for radar performance prediction. Using the radar clutter return to estimate refractivity gives s a real-time estimate of the refractivity.

RELATED PROJECTS

Refractivity Data Fusion and Assimilation (Ted Rogers, SPAWAR): This project is concerned with near real-time techniques for inferring refractivity parameters from radar sea clutter.

REFERENCES

[Anderson 1995] K.D. Anderson, Radar detection of low-altitude targets in a maritime environment, IEEE Trans. Antennas Propagat., vol. 43(6), pp. 609--613, June 1995.

[Box and Tiao 1992] G.E.P. Box and G.C. Tiao, Bayesian Inference in Statistical Analysis, New York: Addison--Wesley, 1992.

[Gerstoft 03a] Gerstoft, P., L.Ted Rogers, W.S. Hodgkiss and J. Krolik Inversion for refractivity parameters from radar sea clutter, Radio Science, 38:1-22, (March 2003)

[Gerstoft 03b] Gerstoft, P., L. T. Rodgers, W.S. Hodgkiss and L.J. Wagner, Refractivity estimation using multiple elevation angles, IEEE Oceanic Eng. (July 2003)

[Gerstoft 04] P. Gerstoft, W.S. Hodgkiss, L.T. Rogers and M. Jablecki, Probability distribution of low altitude propagation loss from radar sea-clutter data, Radio Science, 39, doi:10.1029/2004/RS003077, Nov. 2004

PUBLICATIONS

[Yardim, 2005a] C. Yardim, P. Gerstoft, and W.S. Hodgkiss, Estimation of radio refractivity from radar clutter using Bayesian Monte Carlo analysis, submitted IEEE J Antenna and Propagation (2005).

[Yardim 2005b] C. Yardim, P. Gerstoft, WS Hodgkiss, A fast hybrid genetic algorithm-Gibbs sampler approach to estimate geoacoustic parameter uncertainties, Underwater acoustic measurements, Crete 2005

[Yardim 2005c] C. Yardim, P. Gerstoft, W. S. Hodgkiss, C.-F. Huang, Refractivity from Clutter (RFC) Estimation Using a Hybrid Genetic Algorithm - Markov Chain Monte Carlo Method, IEEE APS international and USNC/URSI National Radio Science meeting, 2005

[Rogers, 2005] L.T. Rogers, M. Jablecki, and P Gerstoft, Posterior distribution of a statistic of propagation loss estimated from radar sea data in press Radar Science, 2005.